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(54) An "in vivo" video camera system.

(57) An in vivo video camera system and an autonomous video endoscope are described. Each system includes a swallowable capsule (10), a transmitter (28) and a reception system (12). The swallowable capsule (10) includes a camera system (24) and an optical system (26) for imaging an area of interest onto the camera system (24). The transmitter (28) transmits the video output of the camera system (24) and the reception system (12) receives the transmitted video output.

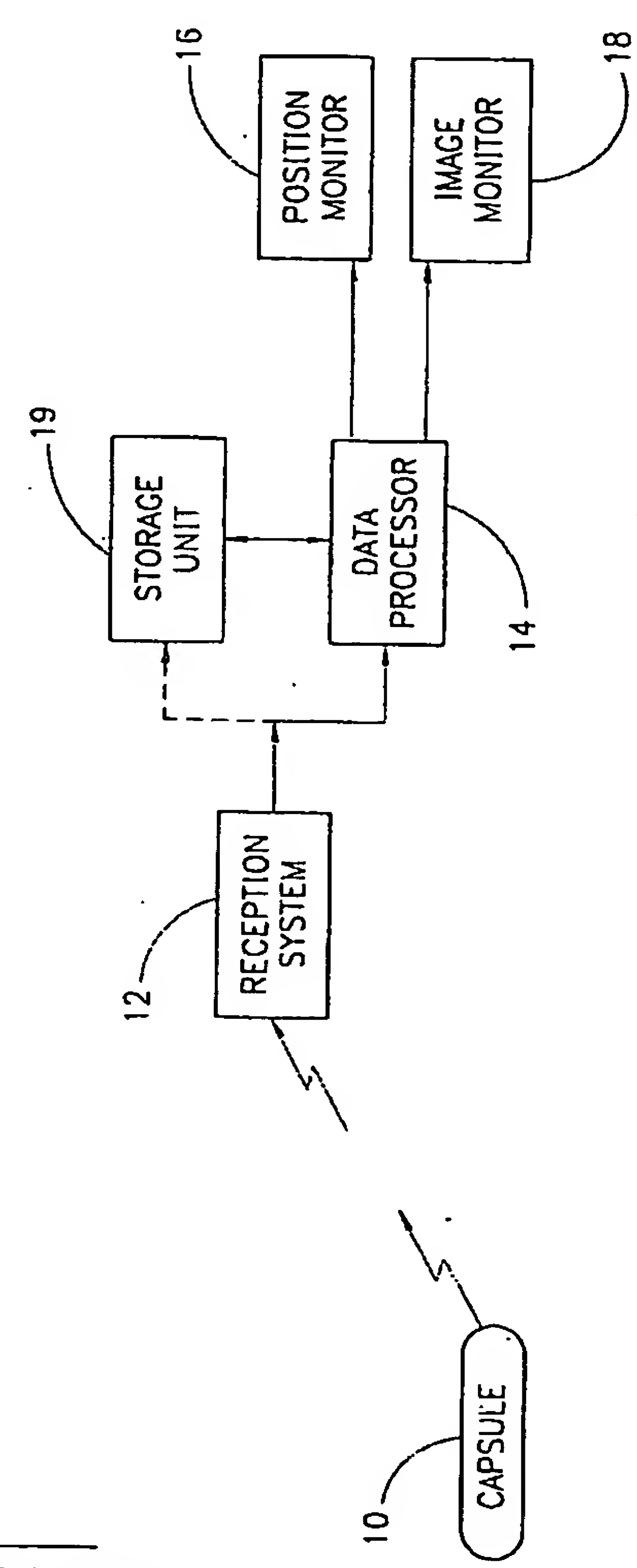

FIG.1

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era capsule forming part of the system of Fig. 1;
Fig. 3A is a schematic illustration of a transmitter forming part of the capsule of Fig. 2;
Fig. 3B is a circuit diagram illustration of the transmitter of Fig. 3A;
Fig. 4 is a pictorial illustration of a portable reception system forming part of the system of Fig. 1;
Fig. 5 is a schematic illustration of a reception system forming part of the system of Fig. 1;
Fig. 6 is a pictorial illustration of an alternative embodiment of the present invention having a stationary reception system;
Figs. 7 and 8 are schematic illustration of calculations performed by a data processor, wherein Fig. 6 is a top view illustration of the antenna array and Fig. 7 is a cross-sectional illustration of the antenna array;
Fig. 9 is a side view illustration of an alternative embodiment of the capsule of Fig. 1 utilizing axicon optical elements;
Fig. 10 is an isometric illustration of the optical paths of four light beams through the optical system of the capsule of Fig. 9; and
Fig. 11 is a schematic illustration of the image received at the detector plane, useful in understanding the operation of the optical system of the capsule of Fig. 9.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Reference is now briefly made to Fig. 1 which illustrates, in block diagram format, an in vivo video camera system, constructed and operative in accordance with preferred embodiments of the present invention.

The in vivo video camera system typically comprises a swallowable capsule 10 for viewing inside the digestive system and for transmitting at least video data, a reception system 12 typically located outside a patient, and a data processor 14 for processing the video data. The data processor 14 typically operates two monitors, a position monitor 16 on which the current location of the capsule 10 within the digestive system is displayed and an image monitor 18 on which the image currently viewed by the capsule 10 is displayed.

The reception system 12 can either be portable, in which case, the data it receives is temporarily stored in a storage unit 19 prior to its processing in data processor 14, or it can be stationary and close to the data processor 14.

Reference is now made to Figs. 2, 3A and 3B which illustrate the capsule and its elements. The capsule 10 typically comprises a light source 20 (Fig. 2), a viewing window 22 through which the light illuminates the inner portions of the digestive system, a camera system 24, such as a charge-coupled device (CCD) camera, which detects the images, an optical system 26 which focusses the images onto the CCD camera system 24, a transmitter 28 which transmits the video signal of the CCD camera system 24 and a power source 29, such as a battery, which provides power to the entirety of electrical elements of the capsule.

The capsule can additionally include sensor elements for measuring pH, temperature, pressure, etc. These sensor elements are described in the prior art.

A suitable small CCD camera system 24 is the 0.25" color CCD cameras of Sony Corporation of Japan. This single chip includes the CCD device and the electronics for producing a video signal from the output of the CCD device. The CCD device can either provide black and white signals or color signals.

Because it is desired to view the walls of the digestive tract, the viewing window 22 typically is located on a side 23 of the capsule 10. Accordingly, the optical system 26 typically comprises a mirror 27 and a focussing lens 29. The mirror 27 is a dichroic mirror which transmits the light from the light source 20, such as a light emitting diode, to the walls of the digestive tract via the viewing window 22. Mirror 27 also deflects the light reflected from the digestive system towards the lens 29. Lens 29 then focusses the light onto the CCD camera system 24.

A suitable transmitter 28 is illustrated in Fig. 3A. It comprises a modulator 30 receiving the video signal from the CCD camera 24, a radio frequency (RF) amplifier 32, an impedance matcher 34 and an antenna 36. The modulator 30 converts the input video signal having a cutoff frequency f_c of less than 5 MHz to an RF signal having a carrier frequency f_r, typically in the range of 1 GHz. After amplification by amplifier 32, the RF signal has a bandwidth of f_c. The impedance matcher 34 increases the impedance of the circuit to match that of the antenna 36.

Fig. 3B illustrates one possible implementation of the transmitter 28 producing less than 1 milliwatt of power. Other implementations are also included in the scope of the present invention.

The transmitter of Fig. 3B comprises two coupled oscillator tanks 31 and 33, each formed of an inductor and a capacitor, wherein oscillator tank 33 includes a variable capacitor 35. Additionally, the transmitter 28 comprises a voltage divider 37, a transistor 39 and an impedance matching capacitor 41.

The two oscillator tanks 31 are connected in a regeneration loop via transistor 39. The voltage divider 37 typically divides the input voltage, typically of 3V.

It is noted that the capsule is moved through the 2digestive tract via the peristaltic motion of the digestive muscles. Since the focal plane of the optical system 26 is fixed close to the housing of the capsule 10, only body parts located close by can be viewed. Thus, the capsule is typically effective only within the small and large intestines.

plane) of the capsule 10 can also be determined using a similar calculation to that illustrated in Fig. 7. A cross-section of the patient 52 is illustrated in Fig. 8. For this determination, four antennas 44e - 44h, which are opposite in a cross-sectional manner, are utilized.

Once again, the ratio of the signal strengths between two antennas which have the transmitter between them is constant along a curve which intersects the location of the transmitter. Thus, antennas 44e and 44h define curve 60c and antennas 44f and 44g define curve 60d.

The location of the capsule 10 thus generated is typically denoted by a two-dimensional vector **Q** having a length Q and an angle ϕ, from the center point O.

The two vectors **P** and **Q** are combined to determine the three-dimensional location of the capsule 10. The location can be displayed two- or three-dimensionally on position monitor 16, typically, though not necessarily, as an overlay to a drawing of the digestive tract.

It will be appreciated that other methods of determining the location of the capsule 10 can alternatively be utilized, as can other reception systems.

Reference is now made to Fig. 9 which illustrates an alternative embodiment of the capsule of the present invention utilizing an axicon optical element. Fig. 9 illustrates the capsule 110 within a flexible tube 112, such as the digestive tract.

Reference is also made to Figs. 10 and 11 which are useful in understanding the optics of the capsule of Fig. 9.

The capsule typically comprises a housing 113, an optical system, described in more detail hereinbelow, the transmitter 28 and the power source 29.

The optical system comprises an axicon optical element 114, which provides the angled front end, a relay lens unit 116, an image detector 118 and a light source 120. The image detector 118 is typically centered around an axis of symmetry 129 which also serves as the optical axis of the optical system. The image detector 118 typically comprises a detector 124, such as a charge coupled device (CCD), and its associated driver 126.

The axicon element 114 is the result of a rotation of a trapezoid around the axis 129. The outer sides of axicon element 114 are angled and, since axicon element 114 is the first element of the optical system to enter the digestive tract 112, axicon element 114 serves to "open up" the collapsed digestive tract 112 through which the optical system moves. As a result, the inner walls, labeled 140, of the digestive tract 112 are pressed against the outer sides of axicon element 114.

The axicon element 114 typically has a borehole 130 in the center thereof which is covered by a rounded cap 132. Axicon borehole 130 can be cylindrical or angled, as shown in the Figures.

Light source 120 is typically located within the borehole 130 and provides light to the axicon element 114. Arrows 138 indicate the directions taken by the light emitted by the light source 120. The light source 120 provides light to illuminate the inner walls 140 of digestive tract 112 which press against the axicon element 114 as the optical system of the present invention passes by. Thus, the object to be detected is present on the surface of the axicon element 114.

The objects to be detected are the inner walls 140 of a digestive tract. Due to the angled shape of the axicon element 114, the inner walls 140 are forced against the outer surface of the axicon element 114, thereby ensuring the creation of an object whose distances to the detector 124 are well defined. However, the resultant object is tilted with respect to the optical axis 129.

As is known in the art, tilted objects form images only on tilted flat detectors placed at an angle to the optical axis. This problem is known in the art as the "Scheimpflug Condition". It is discussed on pages 812 - 813 of the <u>Manual of Photogrammetry</u>, Vol. 1, Third Edition, American Society of Photogrammetry, 1966, which book is incorporated herein by reference. Specifically, the Scheimpflug Condition requires that the tilted object plane, the principal lens plane and the image plane must concur at a point. When imaged with conventional lenses, conical objects form conical image planes which, in turn, produce distorted and defocussed images on a flat detector.

In addition to creating the shape of the object to be detected, the axicon element 114 compensates for the conical shape of the object. This compensation is provided by the fact that the axicon element 114 is a "wedge" rather than just a conical surface. The wedge ensures that beams originating from different parts of the tilted object follow different length optical paths, the optical lengths being designed to generally compensate for the Scheimpflug Condition. Thus, the axicon element 114 produces a perpendicular object and enables the relay lens unit 116 to form an image on the detector 124 when detector 124 is perpendicular to the optical axis 129.

The relay lens unit 116 is a wide angle relay lens unit which reduces the size of the perpendicular object produced by the axicon element 114. It also serves to reduce the optical aberrations of the optical system to a minimum. As shown in Figs. 9 and 10, the relay lens unit 116 comprises two lenses 141.

The axicon element 114 images a torus-shaped image onto detector 124. An example of such a torus-shaped detected image is illustrated in Fig. 11. The torus-shaped image has a hole 142 due to the presence of borehole 130.

In the example of Fig. 11, the blob labeled 144 is currently close to the borehole 130 and the blob labeled 146 is currently close to the outer edge of element 114. As the optical system moves further into

and a borehole centered around said axis of symmetry.

10. A system according to claim 8 and also comprising a light source located within said borehole of said axicon optical element.

11. A system according to claim 8 and wherein said axicon element is located before said relay unit and said camera system thereby to enter said flexible tube first and to open up said flexible tube if it has collapsed.

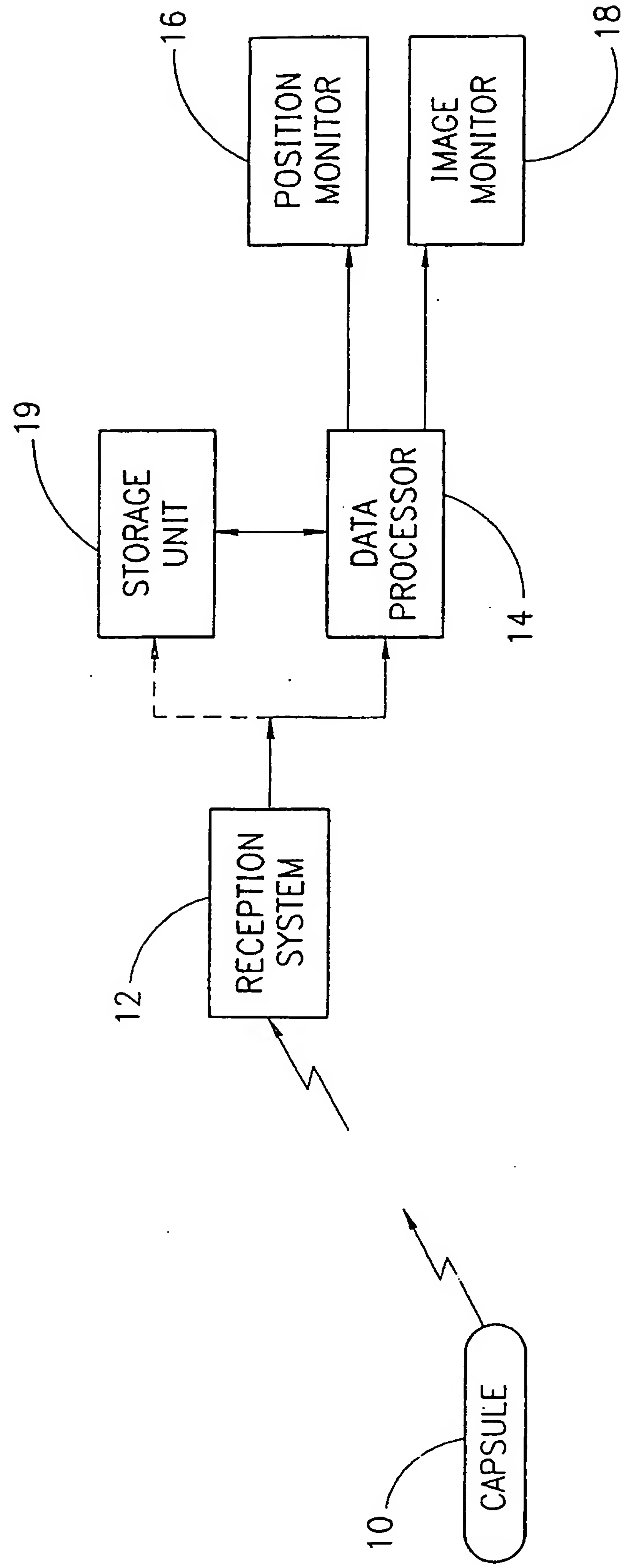

16
POSITION MONITOR
18
IMAGE MONITOR
19
STORAGE UNIT
DATA PROCESSOR
14
12
RECEPTION SYSTEM
10
CAPSULE

FIG.1

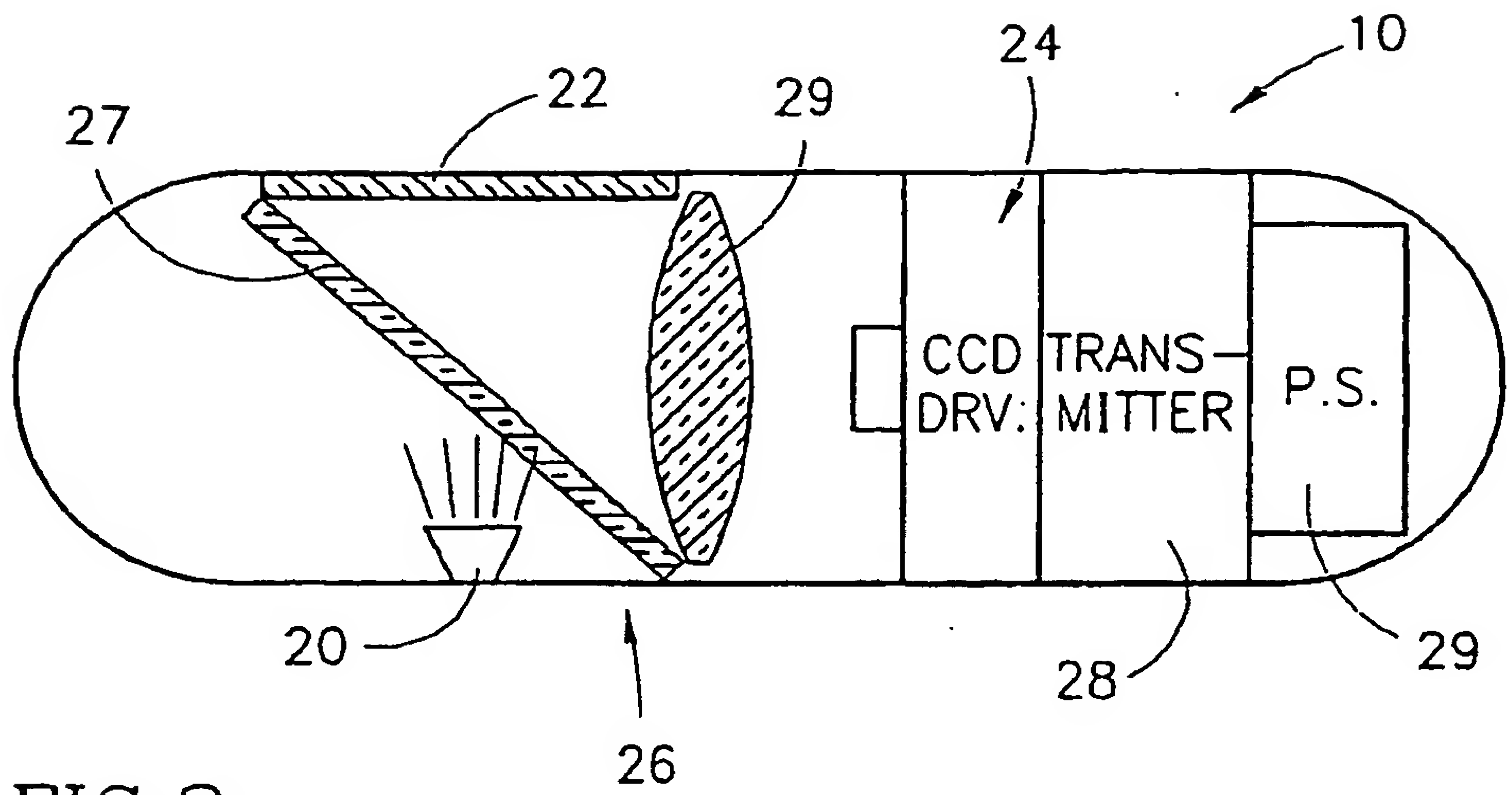


FIG.2

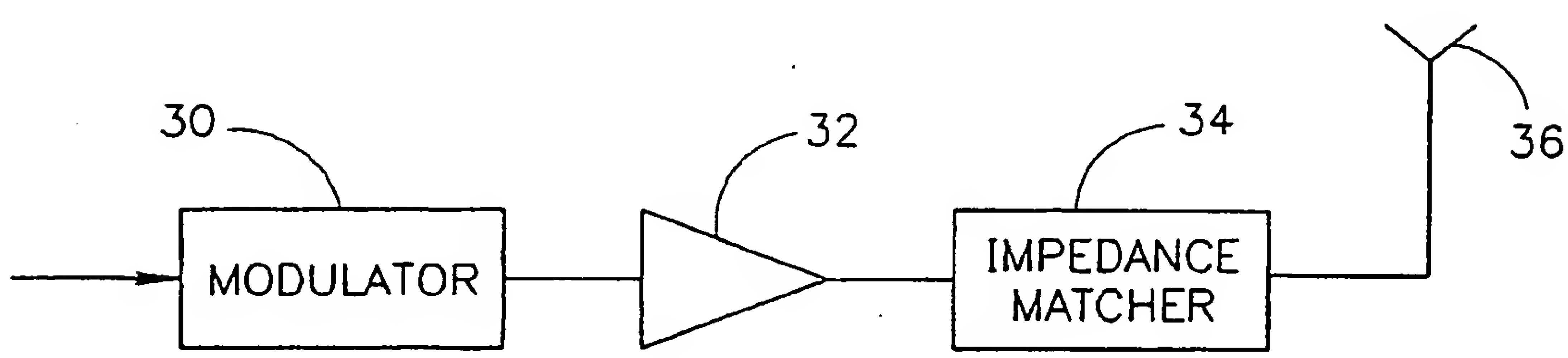


FIG.3A

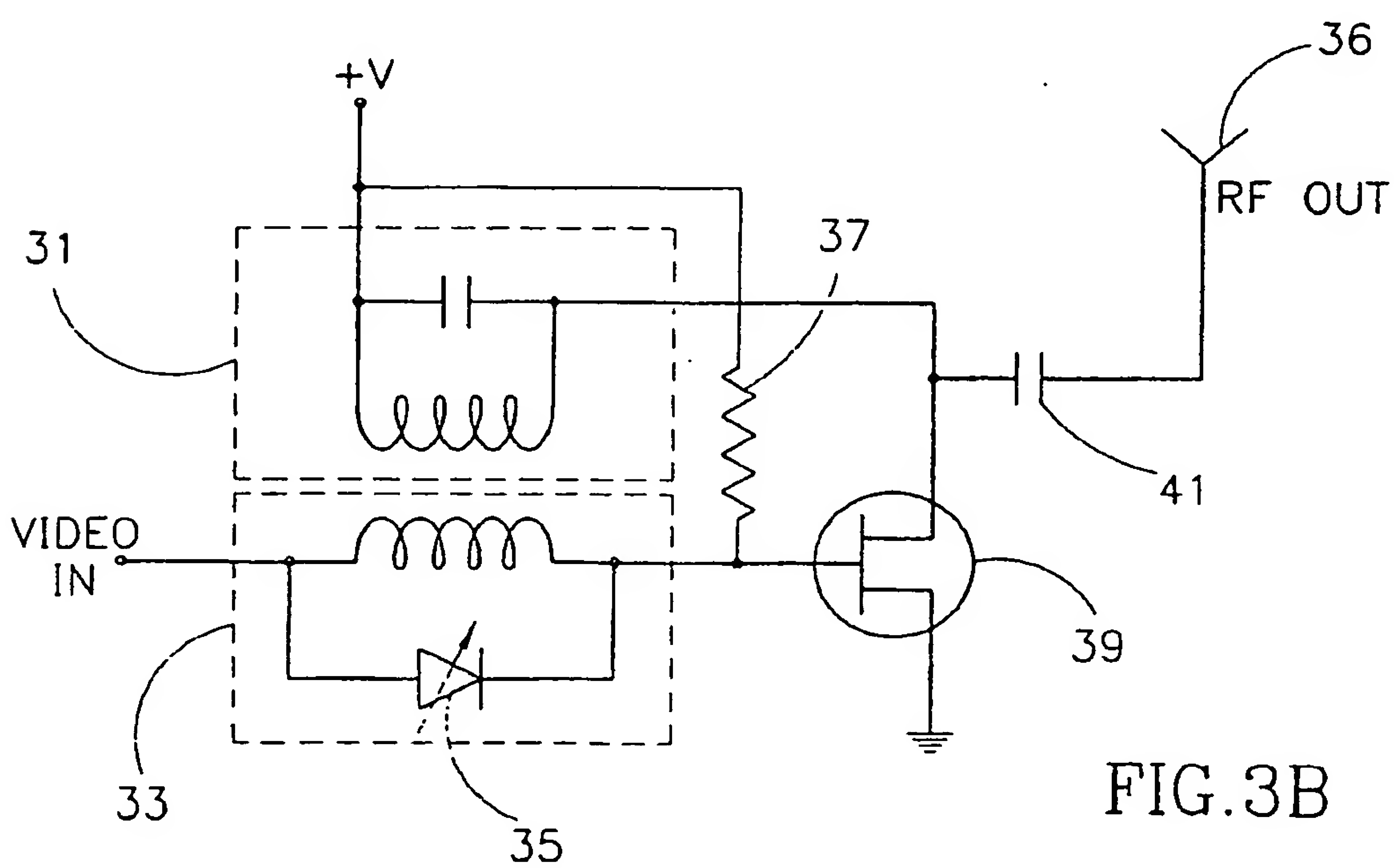


FIG.3B

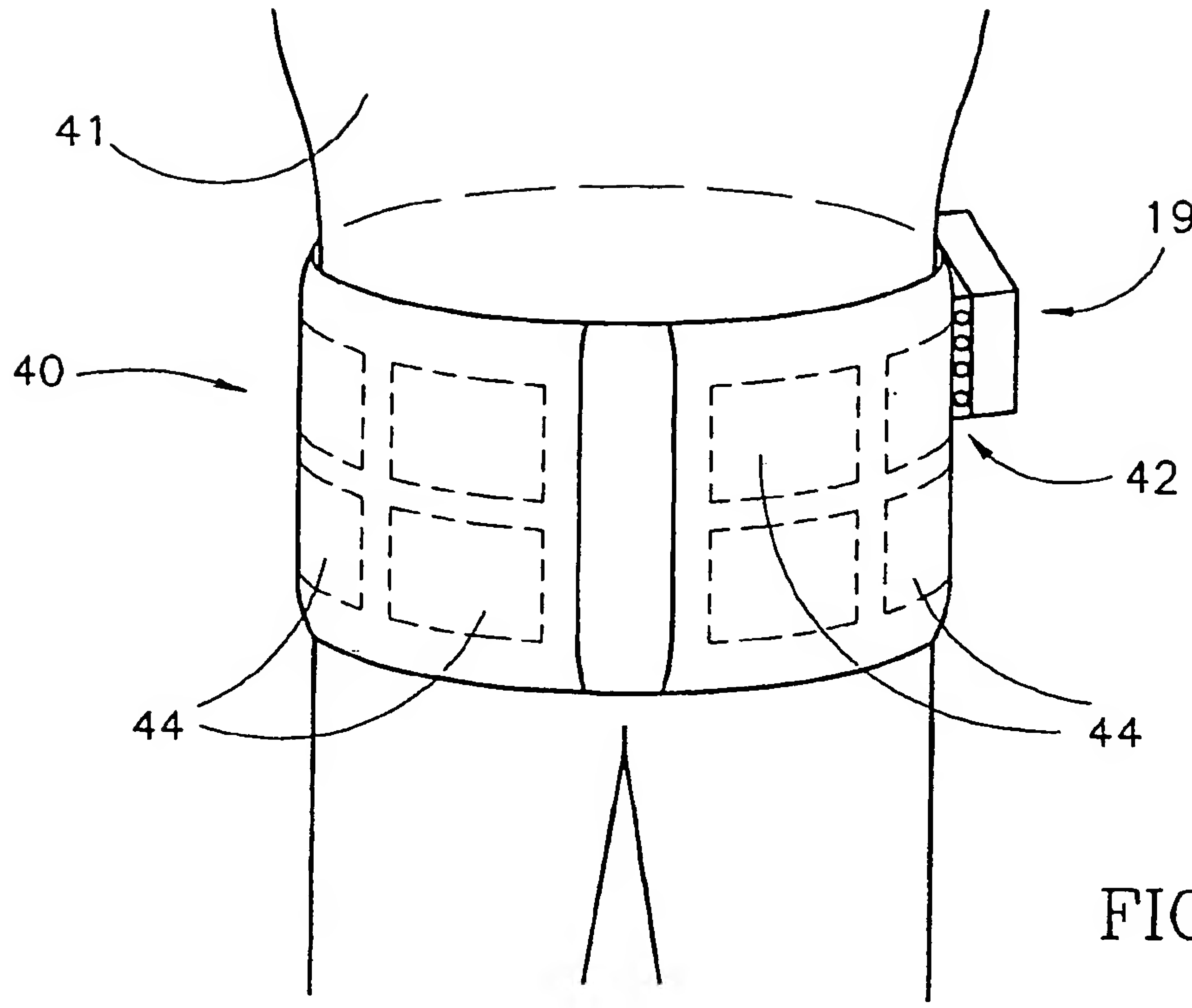

41
19
40
42
44
44

FIG.4

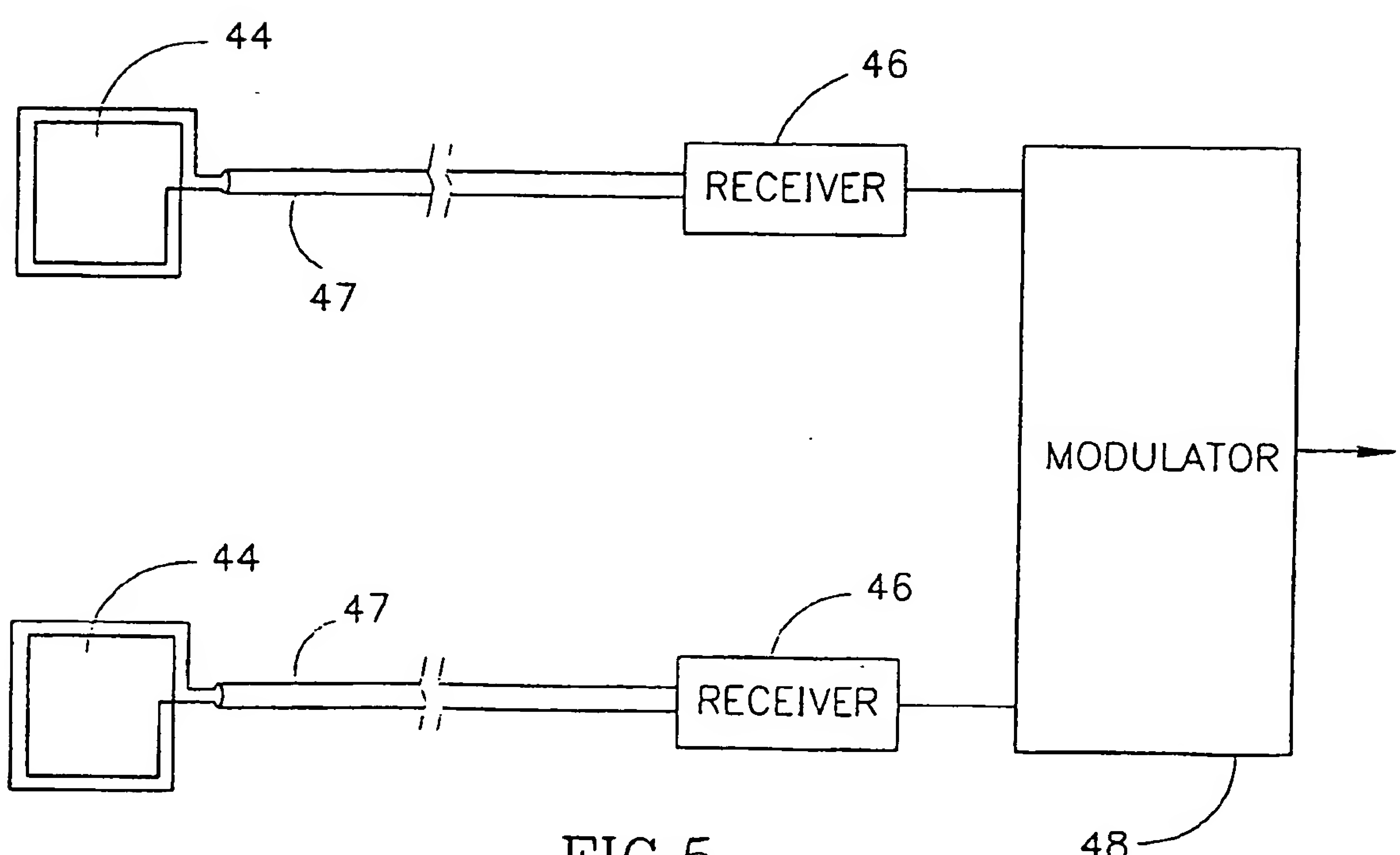

44
46
RECEIVER
47
MODULATOR
44
47
46
RECEIVER
48

FIG.5

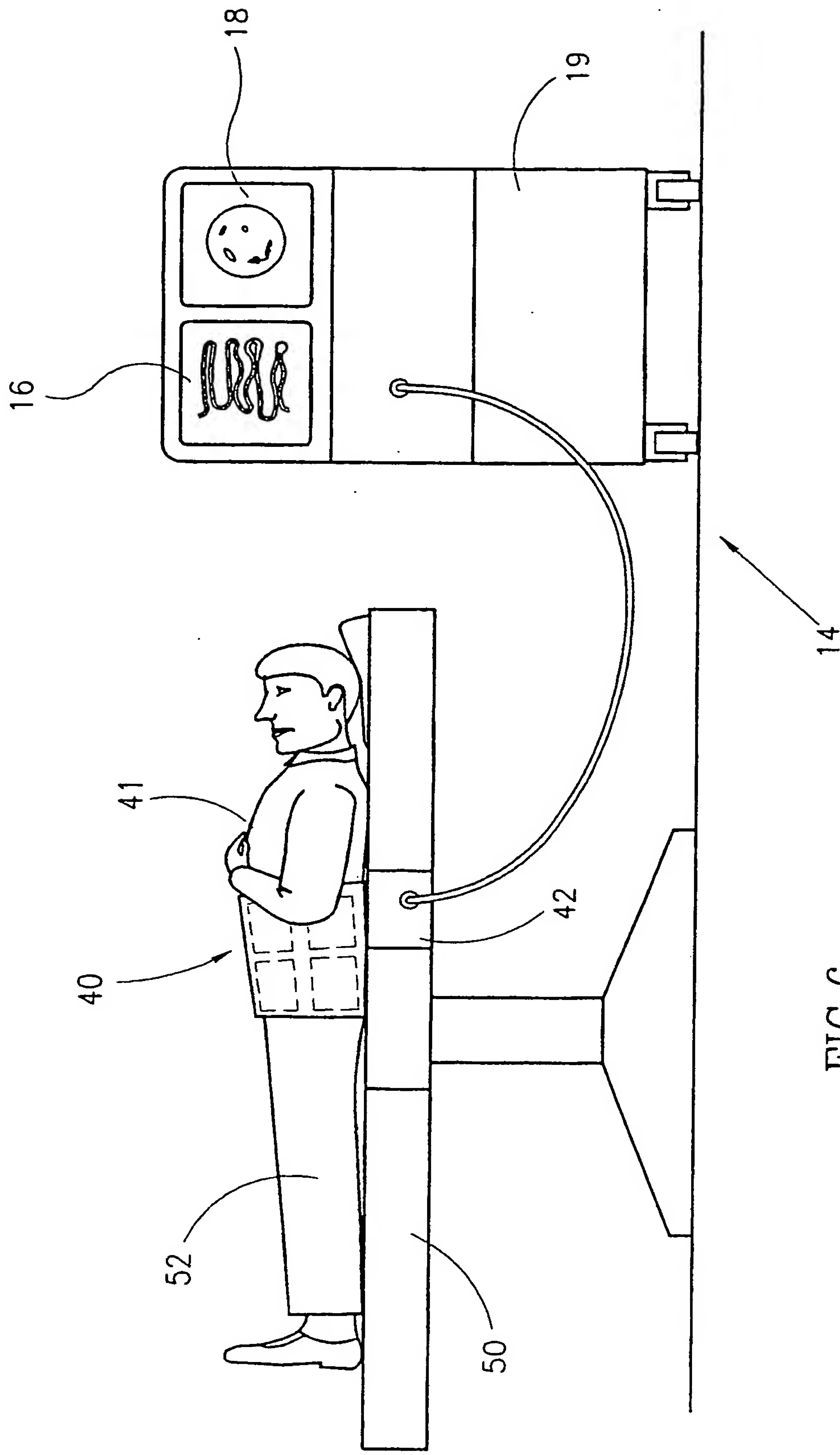
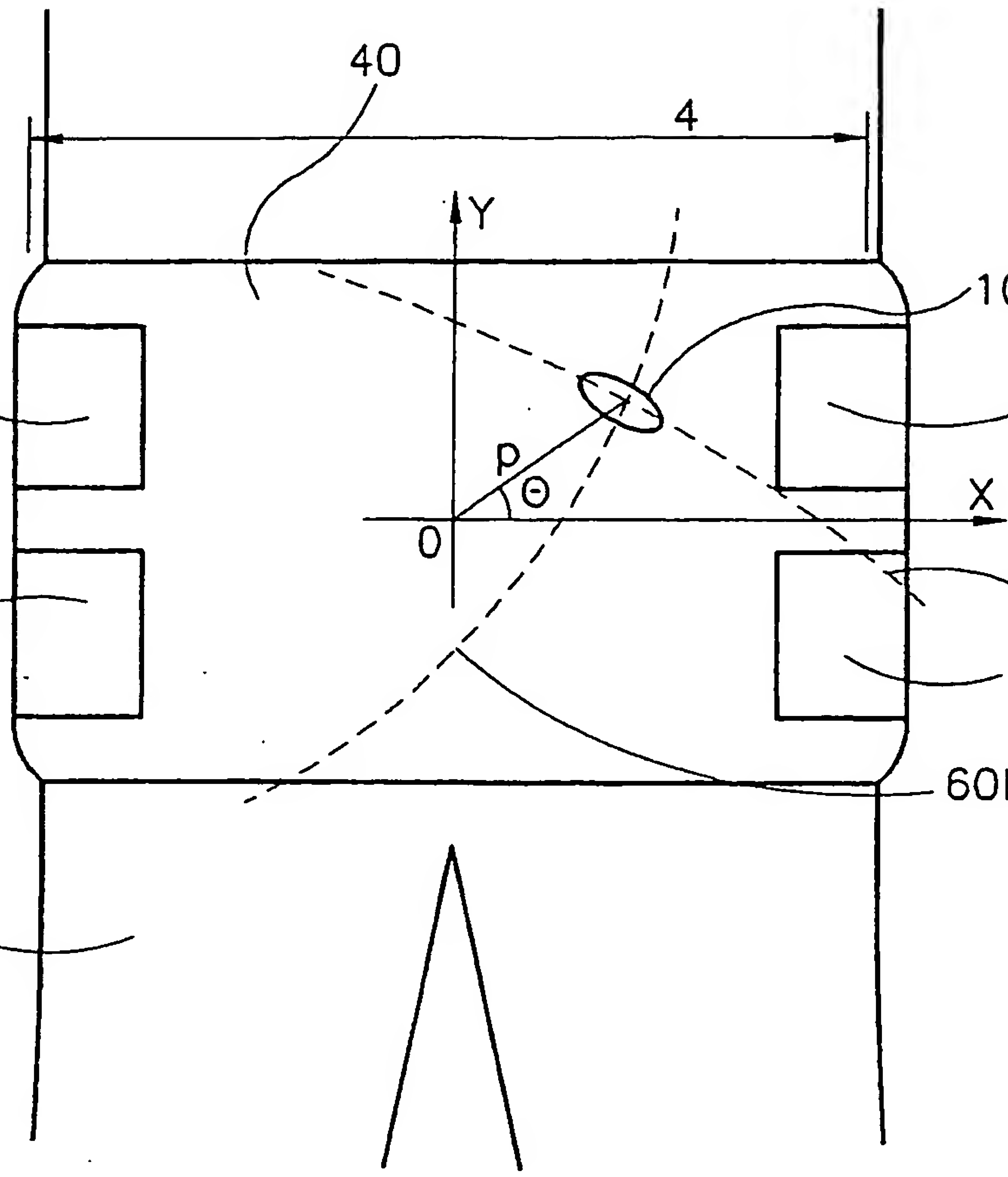


FIG.6

FIG.7


40
4
Y
44b
10
44a
p
Θ
X
0
60a
44d
44c
60b
52

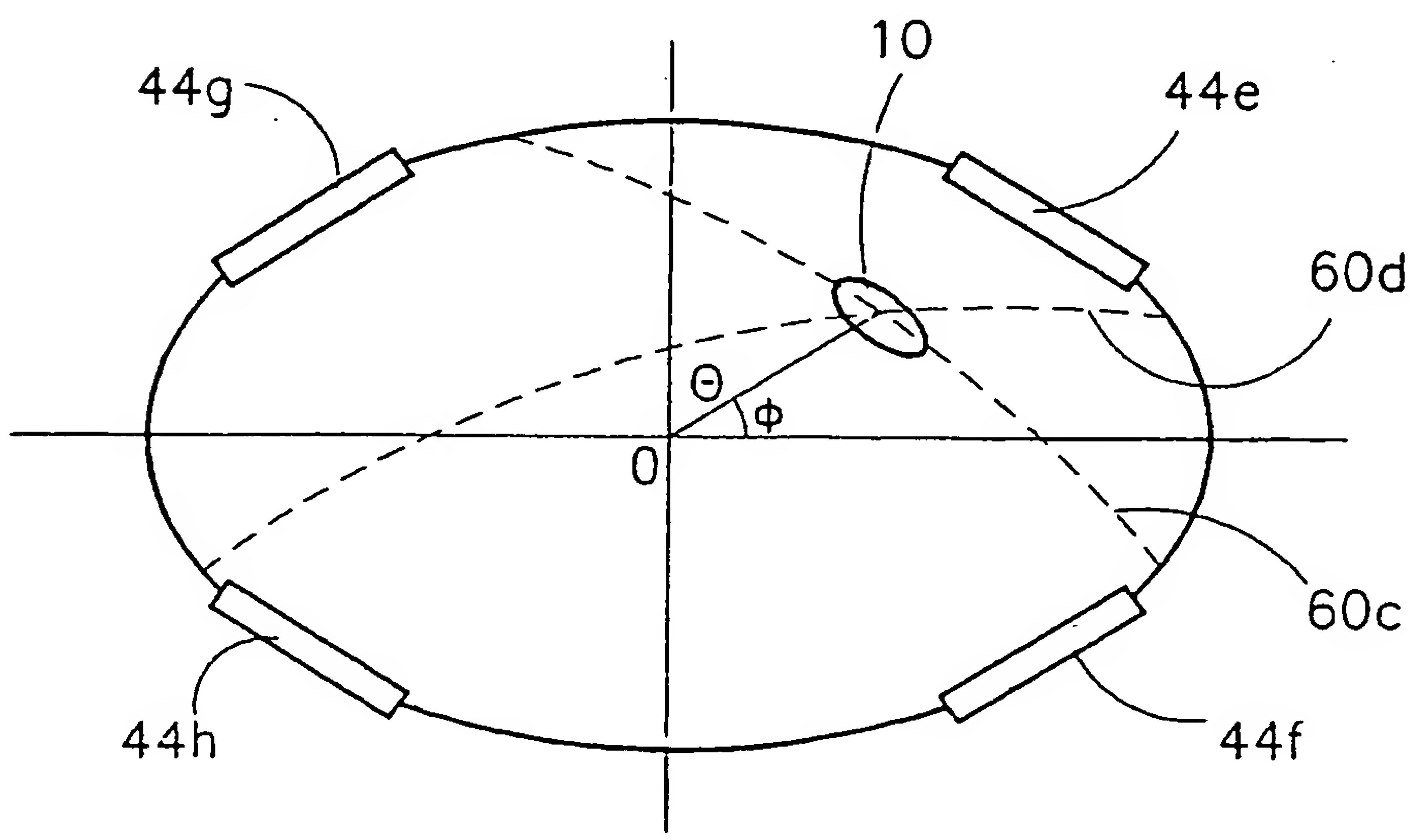
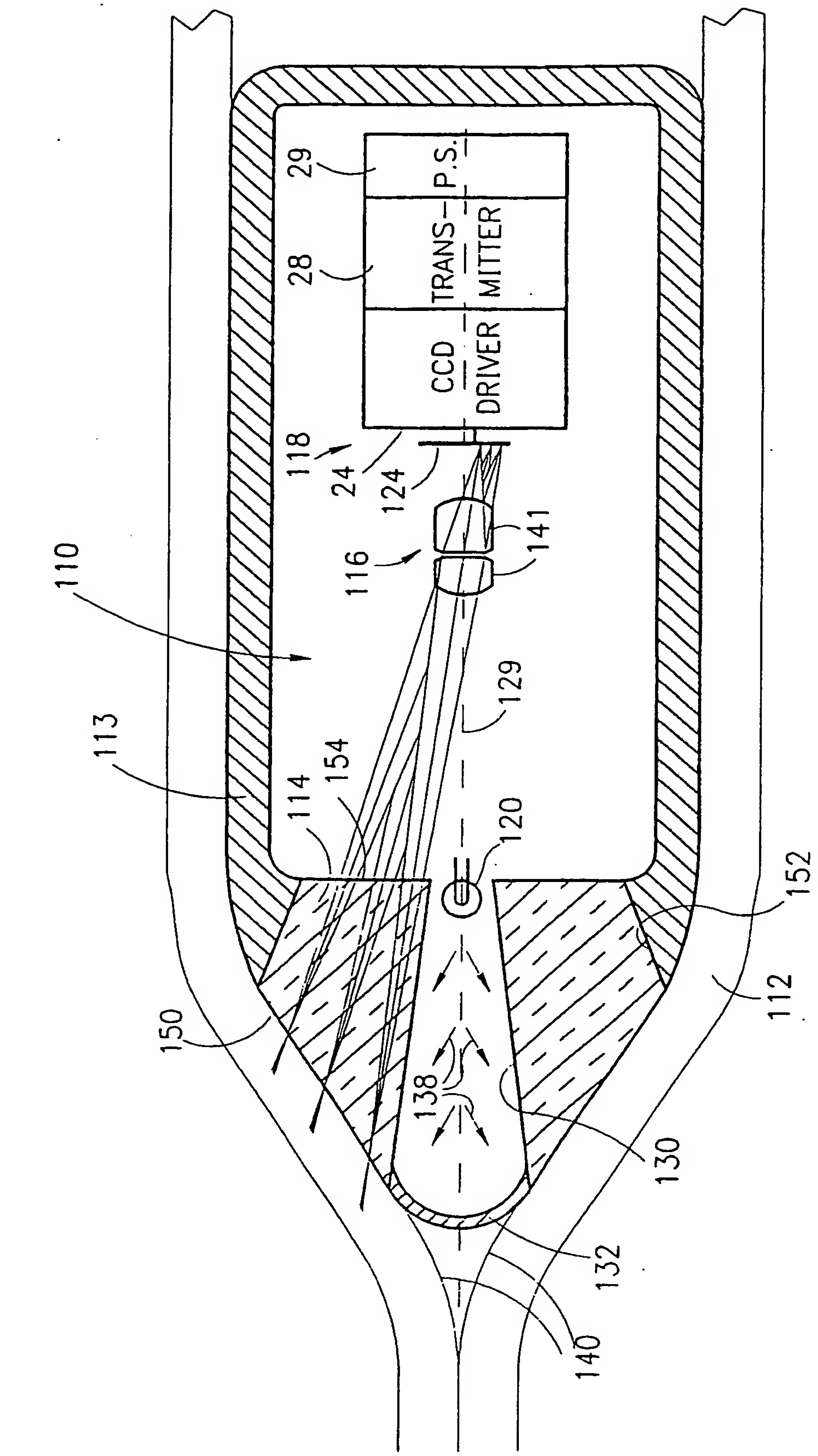

10
44g
44e
60d
Θ
Φ
0
60c
44h
44f

FIG.8



110
113
114
154
150
116
118
24
124
141
141
129
120
152
112
138
130
132
140
29
28
P.S.
TRANS-
MITTER
CCD
DRIVER

FIG.9

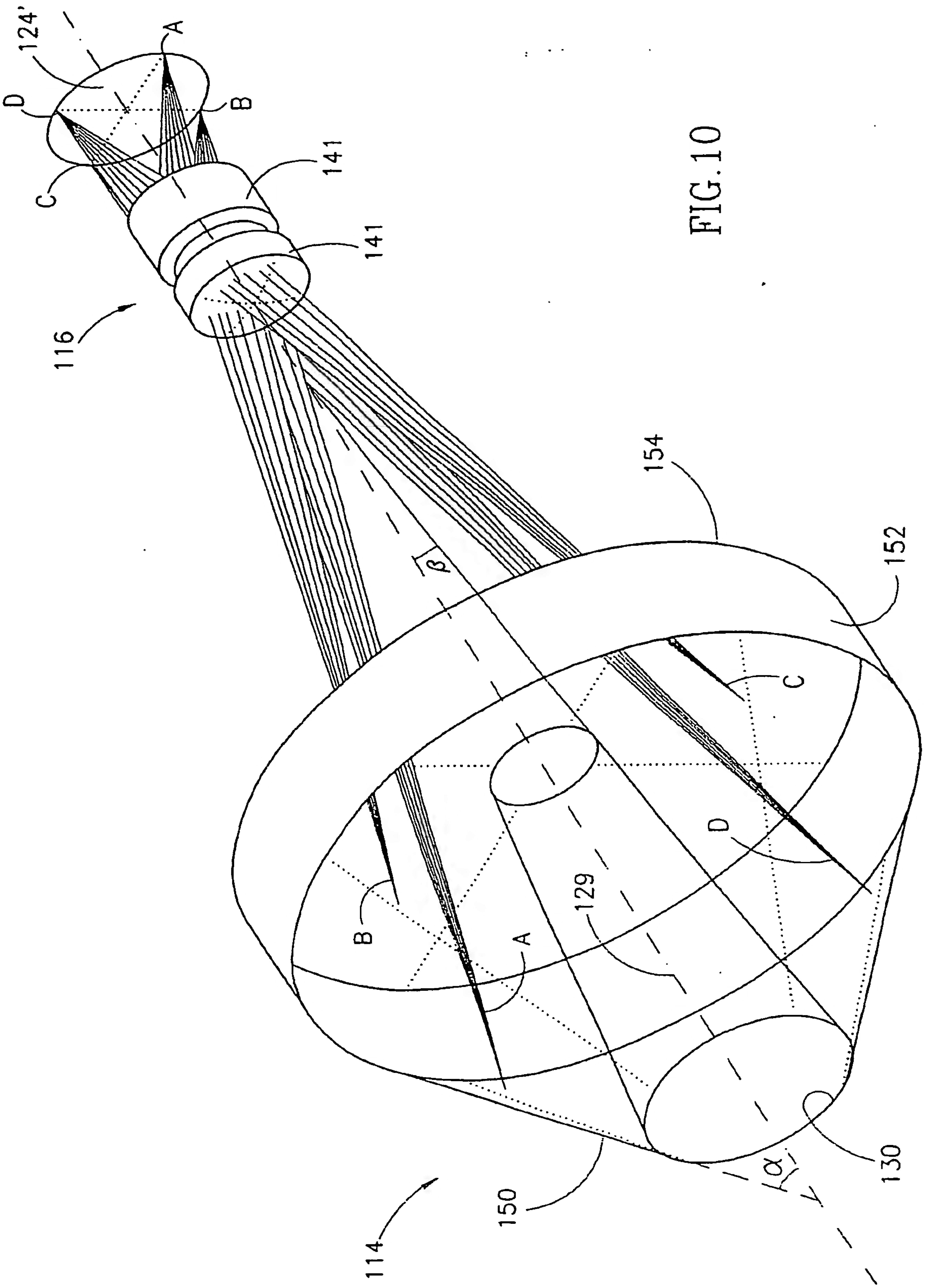


FIG.10

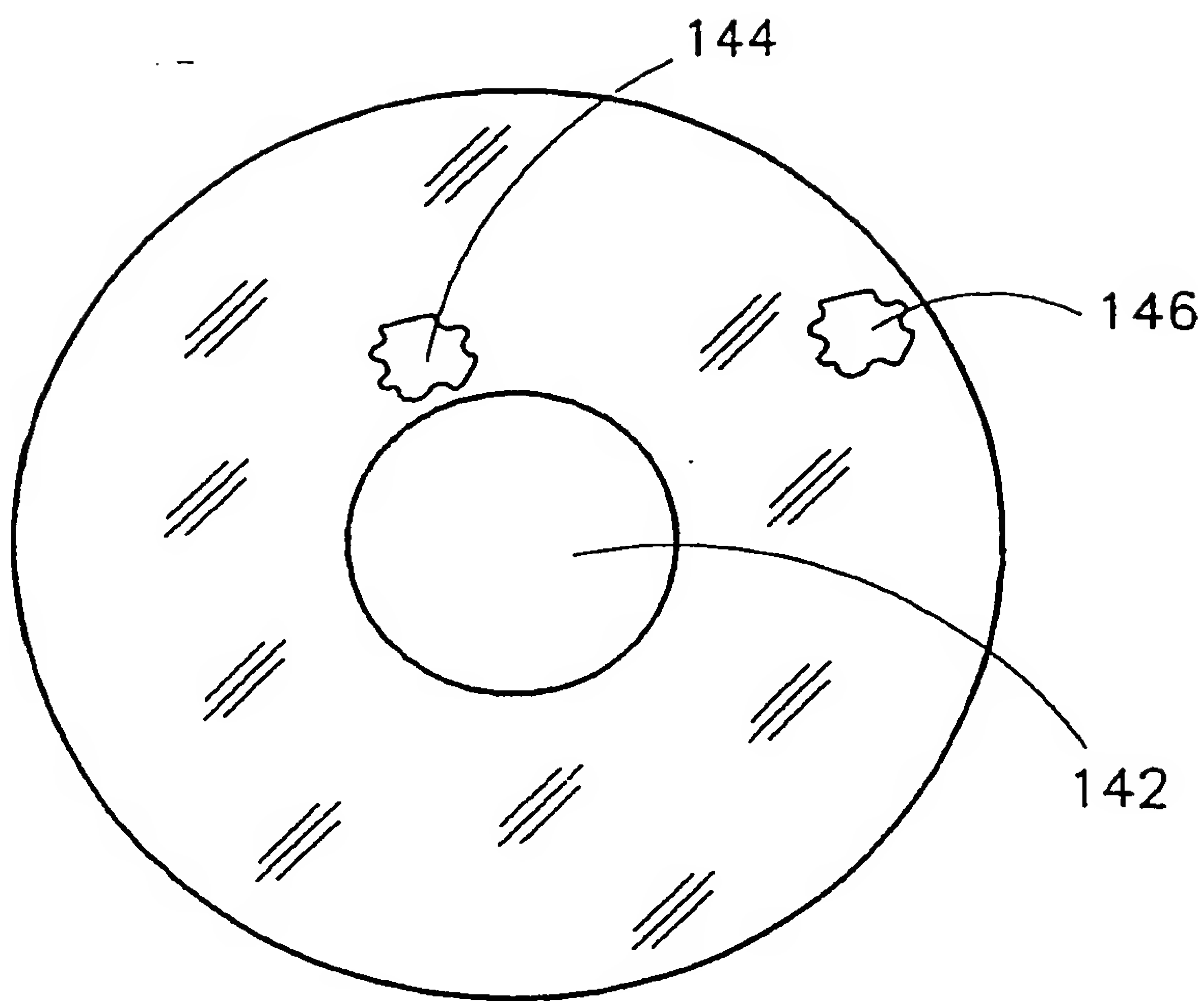


FIG.11